IFDM System Design Considerations

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Chapter 3. IFDM System Design Considerations

A. Introduction

The design of an IFDM system requires the input from a number of professionals: soil scientists, agronomists, and irrigation and drainage engineers. It requires input from practicing growers with the general knowledge required to operate successful farming operations and a farmer with the ability and interest needed to introduce and work with innovative new concepts.

The objective of this chapter is not to describe the detailed design of an irrigation or drainage system. Instead, it will highlight procedures and considerations needed to arrive at the specification of a design. The procedures and investigations needed to make a detailed design of an irrigation or drainage system are well developed and are available from a wide variety of manuals and technical books. A sample calculation of the design flows associated with typical irrigation systems and their management is provided in Appendix pages A-10 to A-21. This sample highlights the data needed for the design of irrigation systems and the flow inputs necessary for drainage system design.

The final product of the design phase is a general arrangement drawing that, with related detailed drawings and specifications, describes a complete IFDM farming unit. A related document describes the operation and maintenance procedures required to ensure the IFDM system will operate properly as designed.

Several steps are needed to complete the design of an IFDM system. The following sections will outline the steps to be considered as the designer goes through the process. Most of the steps are obvious and are part of a routine investigation and design. These are provided solely for assistance in the process and are not to be construed as being a requirement of the design.

B. Analysis of Existing On-Farm Irrigation and Drainage Systems Operation

One of the first steps is the design to determine need and potential scope of a drainage water disposal problem based on an analysis of existing water management conditions. It is essential to consider that an IFDM system might be necessary to continue a farming operation, but this will be at a cost. The net return on the farm will be maximized by keeping the size of the least productive components of the IFDM system as small as possible. This suggests that "source control" will be a critical component of the implementation of an IFDM system.

C. IFDM Analysis and Design Checklist

The following checklist gives suggested steps in the determination of the need for and scope of an IFDM system and the selection of the appropriate components. The intent is to give the consultant an overview of the process needed to complete a successful design of an IFDM system, but is not meant to be considered the only way. Designs and considerations taken during the design will be provided in subsequent chapters for the purposes of illustration only. The resulting analysis and design are the sole responsibility of the designer in consultation with the farmer. The design process will likely follow these steps:

- Farmer inquiry – The farmer requests the assistance from the consultant.
- Regulatory review – After discussion with the farmer, the consultant reviews the applicable water quality regulations and directives covering the design, installation, and monitoring of the IFDM system with particular emphasis on the requirements for the solar evaporator.
- Review and analysis of the existing irrigation and drainage systems – The consultant in cooperation with the farmer will analyze the existing irrigation and drainage system operation to determine the water quantity and quality status. The initial analysis can be done using a simple water balance based on farmer-supplied data. This analysis should be completed prior to advancing to the design. In addition to the irrigation system analysis, the existing drainage systems need to be analyzed (see Appendix pages A-7 to A-8 for system analysis questions). Any mobile lab data on irrigation efficiency would be used at this stage. At this point, the farmer's future goals for cropping and irrigation management should be determined.

- Based on the analysis of existing systems, develop preliminary cost estimates to upgrade or to change the irrigation system to minimize deep percolation and surface runoff. Cost estimates are needed for installation of new drainage systems and retrofitting existing systems for water table management and the construction of a solar evaporator.
- Farmer decides to proceed.
- Meet with Regional Water Quality Control Board (RWQCB) staff to discuss conditions and regulations and file a Notice of Intent and request permits to install IFDM system (Fig. 3-1).
- Complete detailed design of the IFDM system. At this stage, there will need to be detailed soil investigations along with monitoring of groundwater depth and quality. Decisions must be made about existing and long-term cropping patterns. A whole farm plan should be developed that identifies fields included in the project and all the project components. Should consider 1-, 3-, 5-, and 10-year plans for irrigation system development.
- Final Design – detailed construction specifications, management and operation plans.
- Operational plans for each of the components need to be developed. Detailed information is needed to complement the irrigation system if new systems are purchased. If drainage system management is included in the project, then operation guidelines will need to be developed and provided.
- Monitoring – This will be a requirement of the Regional Water Quality Control Board but will be important for the correct operation of the entire system. Water balance data will need to be collected. Soil salinity will need to be monitored in each area. If reclamation is a part of the design, monitoring of the soil salinity will be essential to manage the irrigation and drainage. These data may be used to determine whether it is time to switch irrigation systems or change cropping to higher value crops.
- There will be reporting requirements for operation of the solar evaporator – Develop forms and schedules to comply with state and local requirements.

Once it has been determined that a new IFDM system will be installed, one of the first steps is to apply for and obtain a permit to construct and operate a solar evaporator. The permitable applicant of a solar evaporator facility has been defined by the State Legislature as a single owner or operator of a geographically contiguous property that is used for the commercial production of agricultural commodities with an IFDM system.

It may be helpful to meet with RWQCB staff prior to submitting a Notice of Intent (NOI) to discuss the regulations and learn about any changes.

File the Notice of Intent (NOI) with the Regional Water Quality Control Board (RWQCB).

The NOI consists of an one-page form (included on page A-95 of the Appendix), plus supporting documentation (see sample Table of Contents for Technical Report for the Design of the IFDM system, Design of the Solar Evaporator, and Operational Plan for the Solar Evaporator on page 3-14).

Fig. 3-1 Procedure of applying for and obtaining a permit to construct and operate a solar evaporator

RWQCB has 30 days to review the NOI and inspect the proposed location.

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NOI in compliance with Solar Evaporator regulations.
(If not in compliance, RWQCB shall issue a written response to the applicant identifying the reasons for non-compliance.
The applicant can then take steps to revise the NOI in order to bring it into compliance.)

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RWQCB issues Notice of Planned Compliance (NPC).

⇩

Begin construction of the solar evaporator and IFDM system.

⇩

Construction completed (request inspection).
RWQCB has 30 days to conduct compliance inspection.

⇩

In compliance with NOI and NPC.
(If the solar evaporator is not in compliance after inspection. RWQCB staff will issue a written response, identifying the reasons for non-compliance. The applicant can then take steps to modify the solar evaporator in order to bring it into compliance with the NO and NPC.)

⇩

RWQCB issues Notice of Authority to Operate (NAO).
(According to the regulations, a NAO may not be issued on or after January 1, 2008.)

D. Review of Existing Farm Irrigation and Drainage System Design and Management

At this step, the designer gathers the data needed for analysis of the existing on-farm irrigation and drainage water management. This is done through a series of interviews with the farmer and with farmer-supplied records covering cropping pattern, salt-affected areas, water deliveries to specific crops, irrigation equipment used, and any irrigation system analysis by the mobile laboratory. Data also will be needed on any existing subsurface drainage systems including fields drained, configuration of drainage system, and pumping records from the drainage systems and drainage water quality.

After the initial meeting, subsequent discussions should address the topic of future plans with regard to cropping patterns, and irrigation system selection and operation. An IFDM system is a water management system designed to discharge and eliminate a minimum volume of water. Therefore, it is critical to determine the quantities and origins of the water to be managed by the proposed system.

There are basically two main sources of excess subsurface drainage water on a farm. The first source will be deep percolation from irrigation management and a lesser extent rainfall, and the second source is lateral flow from adjacent areas. It will be reasonably straight-forward to estimate the losses from the first source, while contributions from lateral flow will be more difficult and will require calculations based on secondary sources.

If the DWR mobile lab has done studies on irrigation efficiency and distribution uniformity in the farmer's fields, these will give reliable data on the existing state of water management. It also would provide suggested areas for improved irrigation water management. These should form the basis for the next step in the analysis, which is a simple water balance on the farm and fields of interest. This should be done for several years of record to discern water flow patterns related to crop and irrigation system management interactions. This analysis will need to be completed for all fields being considered for inclusion in the system.

It is important to note that total elimination of deep percolation is not desirable since some deep percolation is required for leaching to maintain soil salinity at desired levels. The question is how much is required? This will be determined by the existing soil salinity, the desired soil salinity, and the irrigation water quality.

This leads to an evaluation of the soil parameters on a given field that will impact the management over the long-term. The analysis should determine the following: Are there any areas with consistently poor yields and problems with stand establishment? If so, what are the probable causes, salinity accumulation, water logging, soil structure? What is the condition of the grade of the soil surface? Simply grading or leveling the surface may be enough to eliminate the problem. Is water logging the result of the lack of surface water control or a rise of the water table?

Salinity problems must be identified so specific remedial action can be applied. Leaching and specific soil amendment program should be specific to the site to minimize the cost of resources. Any available soil data should be consulted to identify layer, compaction, and geologic features, i.e. sand stringers. Soil maps and aerial photographs will assist in this process.

The last part of the analysis will focus on the shallow groundwater response and management for the drained fields. The first question will be to determine the design configuration. How deep are the laterals? What is the lateral spacing? What size are the laterals?. What is the lateral configuration relative to the surface grade? Are the laterals placed to run perpendicular to the surface grade or parallel to it? What is the quality of the water being pumped from the drainage system? What is the monthly pumping rate from the field? How does this correlate to irrigation management? Consider plotting volumes of applied irrigation water and volumes of drainage flow on a monthly basis and look at the ratio. Is it consistent, or does it vary during the season and how does it vary?

In the fields with no subsurface drainage system, what is the depth to the water table throughout the year? Does it negatively impact field operations? Is the water table close to the soil surface in the spring and recede over the cropping season? What is the quality of the groundwater?

After collecting these data the designer should be able to develop a water management strategy as a basis for a preliminary analysis for a discussion with the farmer. These analyses can then be used as a basis for a final design for any required structures and water management recommendations. The initial analysis also should include a map of the farm. Any available regional groundwater flow data should be detailed on this map. At this point, the designer can make some preliminary estimates on designs for any system modifications or new systems that may be required.

The designer needs to determine what improvements can be made on the existing system and what will be the impact of these improvements on the deep percolation losses. As a first estimate research publications and Cooperative Extension Bulletins will provide a guide to reasonable values for irrigation efficiency and distribution uniformity for various systems and soil types. At the end of the analysis for each field, the deep percolation and subsequent drainage volume should be summed to begin the calculation for field sizes for the final stages in the system.

The comparison of the potential improvements in water management between the existing and proposed irrigation systems should be reasonably straight forward by using a water balance approach based on the data from the grower and suggested irrigation efficiencies and crop water used data available from Cooperative Extension. The drainage system will be more complicated, since fields without a system will require a decision to install a system and on what criteria. Will the existing irrigation system and management be maintained or changed? The design must be completed using both criteria. The management assumed for the irrigation will drive the drainage design criteria and the ultimate design.

The drainage system design will require answers for the minimum root depth to be protected, the ultimate water table depth, leaching requirement/leaching fraction, and whether the water table position will be controlled. Crop water use from shallow groundwater is a possibility that must be included in the operation and design. There is also the possibility the soil may need to be used as a reservoir to regulate drainage flow later in the season. All of this will affect the lateral depth and spacing, and ultimately the initial cost and operation. The designs can be done using a transient analysis design program from the USBR.

The analysis for an existing drainage system is more complicated because the design criteria used in the initial construction may be significantly different than those that will be adopted for an IFDM system. The design may have been based on the deep percolation losses from a furrow irrigated cotton field with a 1/2-mile run length and no tailwater return system. Additionally, the laterals were installed parallel to the field surface grade. The final IFDM design might be for a tomato crop irrigated with a drip system. As a result, there will be reduced deep percolation losses, so there may be storage capacity, which may be advantageous but the installed configuration will make it difficult to take advantage of that fact.

The data from the analysis of the irrigation and drainage system will need to be evaluated to quantify the existing system and project benefits resulting from improved irrigation and the cost associated with drainage improvement. The ultimate number will be the volume of water for disposal through each of the reuse areas and the evaporator.

The analysis to this point has focused on those areas to be included in the salt-sensitive crop production area that will be the principle source of drainage water requiring disposal. After the preliminary designs for the first production area have been completed, the analysis can proceed to the first reuse area where saline water will be used for production of salt-tolerant crops. The cropping and size of the first reuse area will depend on the salinity and volume of the drainage water being collected from the initial use. The subsurface drain specifications in the first reuse area may differ from those in the initial production areas because of the need to move potentially larger volumes of water through the soil profile. The cost of new drains in the first production area can be minimized by having high levels of water use efficiency and minimum deep percolation losses. Existing drainage systems were probably designed for deep percolation from less efficient irrigation system and would be adequate for the first reuse area deep percolation losses. Subsequent reuse areas with halophytes also will require extensive drainage systems because of the need to move even larger volumes of water through the profile to maintain soil salinity level. A field with high salinity should be considered for the last reuse area prior to discharge to the solar evaporator. This will require minimum leaching at startup and lower LF to sustain production.

The solar evaporator location will require careful siting. Ideally, it will be placed on unusable or severely salt-affected soil. However, state regulations will govern the siting by requiring the site be protected from overland flows resulting from runoff created by the 25-year 24-hour rainfall event. This may require construction of channels and berms around the site. Historical runoff data and topographic data will be required for the analysis. (See Appendix pages A-22 to A-25 and the CD describing DWR's solar evaporator design.)

Alternative irrigation and drainage design strategies should be developed based on the farmer's experience with drainage flow and water table response and alternative water management practices. Field data might demonstrate a high shallow water table condition early in the growing season with increasing depth to water later in the season where the theoretical calculation would suggest a different scenario. This will have a significant impact on the operation of the IFDM system and the total drainage flow. This is particularly true with furrow irrigation or system operated with low frequency that requires soil water storage to supply crop water. The soil water storage volume increases as the plant root zone develops and the applied irrigation does not completely refill the root zone, and the deep percolation is eliminated. This is not the case early in the season when furrow irrigation applies water in excess of the available soil water storage and large deep percolation results. There may be very little deep percolation with a sprinkler or drip system because the total infiltrated water is not controlled by the soil but by the system operation. In this case the depth and time of deep percolation may be better predicted. This is one example of the considerations that need to be explored with the landowner.

E. Irrigation System Selection

To date, IFDM systems have used surface, overhead sprinkler, and drip/micro irrigation systems in various production areas and in the solar evaporators. A critical requirement of the system selected is that it must be highly controllable and efficient. This section describes irrigation systems that are being used in IFDM systems in the San Joaquin Valley of California. In this case, the systems selected have a demonstrated capability to deal with relatively low intake rates on flat to slightly rolling field conditions. Irrigation expertise should be consulted to verify the suitability of systems selected on specific projects.

The quality of the irrigation system performance has a major affect on the economic feasibility of installing an IFDM system. The lack of quality in the irrigation system performance results in larger drainage flows from each production area with larger flows being delivered to the solar evaporator and the increased costs associated with processing them. Quality in this case is defined as the ability of the irrigation system to apply water uniformly in a controlled manner that minimizes deep percolation. While the individual production areas function primarily for the purpose of generating crop revenue, a secondary purpose is to reduce the volume of water through evaporation and evapotranspiration thereby minimizing the volume of water and salt sent to the evaporator. In the context of the IFDM system, other losses, such as pattern and operational losses and tailwater, are not in fact losses because of the presence of the drainage system and tailwater return systems. They are significant however in that they affect the required design capacity of the hydraulic components. In the case of the solar evaporator, special windbreaks, including physical barriers, may be required downwind of the spray field.

Representative irrigation system alternatives and their operational characteristics are:

- **Buried Drip Irrigation**: Drip irrigation systems have been gaining favor in the Valley because of their inherent qualities of good water control and efficiency despite their relatively high cost. Recently the development of GPS equipment has allowed for buried drip systems while still accommodating the cultivation of a variety of row crops and extending the life of the system now estimated to be 4-5 years. Representative system specifications are as follows:

  Wall thickness, 10-mil.
  Outlet spacing, 12-in.
  Flow rate, 0.22 gpm per 100 ft at 8 psi
  Application rate, 0.042 in./hr (at 60 in. row spacing)
  Tape Size, 7/8-in.
  Depth of bury, 8- to 15-in.
  Tape length, 1,200-ft –to-1,300-ft
  Field slope, 0.1 to 0.2%
  Performance data: Pattern loss, 10-15%

Note: Pattern loss assumed to be 10% in the sample calculation in Appendix (pages A-10 to A-21). Pattern loss results from a variation in emitter discharge caused by friction losses in the tubing and between sub-mains.

- **Sprinkler Irrigation**: For a variety of reasons, Valley farmers favor portable aluminum pipe systems in a semi-solid set configuration using low capacity sprinklers. In some cases, pipe is rented for the cropping season, installed as solid-set, with irrigation achieved by valve operation only. In other situations, the mainline is installed for the cropping season to service portable, hand-move laterals. Portable systems are favored because of their inherent flexibility, particularly as relates to accommodating farming operations. In some cases, chemically aggressive waters can significantly shorten the useful life of portable aluminum piping systems. Recent development of portable PVC irrigation systems could provide a satisfactory alternative in this situation. Representative system specifications are as follows:

  ____ Sprinkler Metal Body, Impact Drive
  ____ Nozzle size, 1/8- in.
  ____ Flow rate, 3.0 gpm (with or without flow control)
  ____ Application rate, 0.24-in./hr

  Aluminum, quick coupling, irrigation piping

  ____ Spacing, 30ft x 40ft
  ____ Lateral size, 3in. to 1,320ft or 4in. to 2,640-ft
  ____ Mainline, 10- in. by 30 ft length

  Pumping unit

  ____ Sprinkler operating pressure, 50 psi
  ____ Capacity, 1,600 gpm/160 ac system (or 0.53 in./hr gross capacity)
  ____ Discharge pressure, 60-70 psi

Performance data: Spray loss, 3.0-6.0%

Note: Spray loss was assumed to be 3% in the sample calculation in Appendix (pages A-10 to A-21). However, this *needs to be verified with knowledge of actual on-site weather conditions (wind, humidity, temperature, and sprinkler drop spectrum). With deep seepage collected by the tile drainage system, spray losses from sprinklers represent the only absolute loss of irrigation water within the system.*

Operational loss, 5-12%

The value reflects water loss in filling the piping network, losses through leaky gaskets in pipe joints, and losses caused by sprinkler differential pressure operation.

Pattern losses, 5-15%

The value reflects water lost below the root zone as a result of the sprinkler non-uniformity of application. Sprinkler distribution patterns are required to simulate actual field performance in the test laboratory. An analysis of this data provides design parameters.

- **Surface Irrigation**: Because of the favorable terrain and relatively low soil infiltration rates, surface irrigation systems have been the principal systems used in the Valley. The preferred water supply configuration uses gated pipe supplying furrows. In general, the field has been graded and smoothed using laser-guided systems to provide the desired furrow slope. Representative system specifications are as follows:

Gated Pipe

____ 8-10-in. portable aluminum mainline with adjustable gates spaced to align with the furrows.

Graded Furrows

____ Aligned parallel with the field boundary

____ Length, 1,320-ft (1,280 ft net)

____ Slope, 0.001 or 0.1%

____ Spacing, 30-, 40-, and 60-in.

Hydraulic Performance

____ Pump capacity, 5.5 cfs/160 ac

____ 200 furrows operating at 12-13 gpm

____ Application rate

Furrow Spacing	Gross Application Rate
(in.)	(in./hr)
30	0.37
40	0.28
60	0.19

____ Gross capacity, 15.4 gpm/ac or 0.82 in./d

Performance Data: Tailwater loss, 4.0-8.0%

Pattern loss, 18.0-26.0%

Losses need to be verified by mobile laboratory studies or as simulated computer studies. Pattern losses are captured by the drainage system for processing in the solar evaporator. This effectively eliminates the usually efficiency penalties associated with furrow irrigation.

After considering the farming operation and long-range goals the farmer, and designer will select the irrigation systems to be used in each part of the IFDM system and proceed with the design using current methods. As the design develops, the farmer and designer should look into the availability of cost-share funds for improved water management through the purchase of irrigation equipment.

F. Farming Unit Design

An example of an approach to determine irrigation and drainage flows for a hypothetical IFDM system sited on 640 acres is provided in Appendix (pages A-10 to A-21). It highlights the impact on water management associated with irrigation system selection, water quality, and cropping patterns. The calculation involves estimating the water requirements, the deep percolation losses, and the resulting size of the production areas for salt-tolerant plants and halophytes. Integration is involved in that after irrigation of salt-sensitive crops there will be successive reuse of drainage water on the salt-tolerant crops and halophytes for disposal. The total number of reuses prior to disposal in the solar evaporator or salt sequestering facility will depend on the irrigation management and the size of each production area.

G. Development of the Farming Unit General Arrangement Drawing

This drawing locates accurately all of the permanent farming unit structures including for example, buildings, civil works, field boundaries, windbreaks, and drainage and is supplemented by detailed drawings where larger scales are required. The drawing gives information on prevailing winds as they affect this setting of specific facilities. It also locates and identifies nearby facilities that could be affected by the operation of the IFDM system. Sprinkler spray drift and dust from farming operations are examples of concerns to be managed. This drawing references the availability of other drawings that could provide information useful to the design engineer for example:

a) Contour maps
b) Soil maps
c) Salinity impacted soils
d) Ground and surface water impacted areas
e) Land use designation maps
f) Historic site identification

This drawing, with related detail drawings, provides a basis for dealing with contractors when portions of the infrastructure are contracted out. It represents a document, which allows for careful engineering review of the interrelated facilities that together make up an IFDM system.

A study by Krauter (2005) found that salt-laden spray drift from the solar evaporator can drift over 600 ft downwind. (See Appendix page A-96 for project summary.) Fine particles (PM_{10} or $PM_{2.5}$) may be transported farther and remain aloft longer, potentially leading to air quality concerns as the amount of water evaporated in the region increases. Efforts can be made to reduce this drift by strategically located natural and mechanical windbreak. The problem also may be managed by careful siting of the solar evaporator. It should be sited internal to the farming unit boundaries such that no spray can leave the farming unit. In addition, the downwind fields should be planted with salt-tolerant crops that are better able to tolerate the salt buildup on the leaves. Further, the solar evaporator design capacity may be high enough to permit the system to shut down during the characteristically high wind periods in the afternoon.

Some systems must be in place to manage storm runoff generated by a 25-year, 24-hour storm on the solar evaporator site. One possible solution would be the installation of graded terraces down slope of the evaporator site. The terraces could deliver the discharge to an operational storage reservoir (also known as a "water catchment basin"). In general, there should be no standing water that persists longer than 48 hours.

When surface irrigation systems are installed, tailwater reuse systems are required to control the movement of tailwater and help maintain the efficiency of the system. The design must deal with any potential off-site surface storm water movement that could impair the effectiveness of system components. Contour maps will help identify vulnerable locations. Operational reservoirs and pumping facilities should be sited out of harms way from storm runoff. Study the movement of groundwater through the site. Consider planting windbreak trees and barrier crops to mitigate the movement of soil and water over the site. Windbreak trees could be especially effective on the upslope boundary of the groundwater surface. In addition to providing a windbreak function they would utilize a portion of the encroaching water of unknown quality.

H. Water Management Options

The objective of the water management in an IFDM system is to move salts through the root zone in the various stages of the system, which will require careful water management. This can be done by implementing one of the following: a water balance procedure; using a soil water sensor; or experience. A water balance procedure keeps track of applied and lost water and sets threshold of water use from stored soil water and then initiates irrigation to replenish this lost water. This will require data from weather stations or through the weekly bulletin provided by the Westlands Water District.

Soil water sensors can be used to set thresholds to initiate irrigation, the limitation with instruments is that data is lacking on the amount of water needed to be applied so another measure is needed.

In some cases, the grower has a history of farming specific soils and crops. He has managed specific fields and recognizes the signs of moisture stress in the crops. This is probably the poorest method to use and will result in excess applications.

While water management schemes are fundamentally crop orientated, they must also manage the following farming enterprise realities:

- Controlling water to influence crop maturity.
- Availability of operating labor.
- Integration of irrigation operation with overall IFDM objectives.

I. Drainage System Design Guidelines for IFDM

1) Introduction

Drainage is used in irrigated agriculture to provide control of shallow groundwater, to maintain an aerated zone in the soil, and to provide for the removal of deep percolate containing salt. These are functions that will be required in an IFDM system. In the past, drainage systems were designed to operate continuously to ensure that the water table position was maintained at a level that would insure aeration and salinity control. Recent research has demonstrated that drains can be managed to restrict flow particularly after irrigation without creating an aeration or salinity problem.

This section will discuss the design of subsurface drainage systems for incorporation in an IFDM system. It will not be a detailed discussion of the mechanics of the design since that topic is well described in technical manuals developed by the U.S. Bureau of Reclamation (USBR) and the Natural Resources Conservation Service (NRCS). The American Society of Agricultural Engineers has also developed an engineering practice (EP) that describes the design, and construction of subsurface drainage systems for irrigated lands. This EP was developed based on the USBR guidelines.

The focus of this chapter will be subsurface drainage but the designer should remember surface drainage also will be a concern. There are details in both the USBR and NRCS technical manuals that describe the design of surface drainage systems. Much of the surface drainage requirements can be met by simply grading of the soil surface. More consideration for surface drainage will have to be given to the area around the solar evaporator and provision will have to be made to control the 25-year, 24-hour flood event. An example design developed by the DWR is provided in Appendix pages A-22 to A-25 and on the CD,and details the procedure for determining the design flood and a possible method of control.

2) Subsurface drainage system design

A subsurface drainage system is designed to maintain a minimum depth to the water table at the mid-point between two drainage laterals and a depth of approximately four feet has been used for most soils as being adequate to prevent soil salination. During the design the mid-point water table depth is the closest that the water table will get to the soil surface on a yearly basis. The remainder of the year the depth to the water table will be greater than four feet. This is the basis for the transient analysis used by the USBR and is the analysis generally used in irrigated agriculture. The analysis method has been computerized by the Irrigation Decision Support Group at Colorado State University and the program titled Agricultural Drainage Planning Program (ADPP) is available on the web at www.ids.colostate.edu. This is the program that was used in the analysis later in this chapter.

The design of a drainage system is reasonably straightforward. It requires a detailed investigation of the field being drained and then an analysis of the cropping and water management to determine the deep percolation. Decisions must be made with regard to the depth of installation and the design can proceed. Use of a program will enable the designer to evaluate alternative designs quickly.

The topography of the area also will be analyzed to identify the potential for surface flows that may impact the design. Detailed site evaluations will determine the geology of the area and the soil type in the field of interest. The geology is critical because it will determine the potential for lateral flow of groundwater but it also determines the location of any impermeable barriers. These barriers are the physical features of the soil profile that restrict deep percolation and cause the perched water table conditions that need to be controlled. If drainage systems are present in the area, data from the design of those systems will be a starting point to determine the extent of any required additional investigations.

The topographic investigation also will determine the surface grade and the low point in the field. The drainage sump will be located at this point. The drainage systems and sumps will be used in the recycling program of an IFDM system. Open channels are used to collect drainage flow discharged from sumps and move the water to another area for blending and recycling. However, this may be problematic in an IFDM system because of the requirement to limit standing water.

The soils data will be used to determine the specific yield (SY) and the water holding capacity of the soil. The specific yield is defined as the volume of water released from a known volume soil under the force of gravity and the inherent soil tensions. This is a dimensionless number that is required in the design process and can be determined in the laboratory or from graphs. The USBR design manual gives a graph of the SY as a function of saturated hydraulic conductivity. The soil water-holding capacity will be used in the water balance calculations to determine the potential for deep percolation losses.

The soil salinity status also will be determined at this time and will be the basis for any required reclamation and for the crop selection. In an IFDM system much of this information will already be known since the fields are in production.

One critical piece of data will be the saturated hydraulic conductivity, and this will have to be determined for each field where a subsurface drainage system will be installed. In the initial design phase of the IFDM system, the saturated hydraulic conductivity can be estimated from the soil type. It will be critical to have field studies to confirm the saturated hydraulic conductivity for the final design. This value determines the flow in the system and underestimating the value will result in lateral spacings that are too close and conversely if the value is too high, the laterals will be too far apart and adequate control will not be possible.

After the physical parameters are established for the site, the water balance components have to be established. These will include the precipitation, the irrigation water losses, and the lateral flows into the region. Laterals flows are difficult to quantify and will probably not be a major component of the drainage flow.

The precipitation and irrigation can be quantified by constructing a precipitation and irrigation schedule that quantifies the volume and timing of water application events. The irrigation schedule will be developed as part of the irrigation system design. The irrigation schedule will include the date of application and the projected deep percolation losses. This becomes a direct input into the drainage design. The precipitation input to the design can be handled similarly to the irrigation schedule by accumulating rainfall and applying it monthly during the winter.

The irrigation schedule must be done for each crop and irrigation system combination that is projected to be used on the site to determine which one will have the largest deep percolation potential. Recall from the irrigation design section the differences in projected deep percolation losses resulting from the inefficiencies of each type of irrigation system. When the inefficiencies are added in terms of the total crop water use the projected deep percolation will indicate which irrigation system cropping pattern will be the most critical in the design process. For example, using surface irrigation on a perennial crop would probably have a greater deep percolation potential than surface irrigation on a short season annual.

The result of the design will be a specification of the depth and spacing of the laterals, the location of the drainage sump, and the construction details for the subsurface drainage pipe. These details are well covered in the aforementioned manuals and within the consultants experience and will not be detailed here. The most commonly used drainage pipe is corrugated plastic, which can be installed by either plowing or trenching. The need for an envelope material around the pipe will be determined based on the soil type at the depth of installation and on local experience. The diameter of the pipe will be designed based on the deep percolation losses. The size for laterals in the field is typically 4-to-6 inches with 10-to-12-inch pipe being used for the sub-main collector to move water to the sumps. The pipe size can be varied in the field to account for increasing flow volumes. There are design graphs to assist in the sizing of laterals and mains. The sump design is straightforward and will require the installation of a pump adequate to handle the design flow and limit switches to control the depth. Additional piping and control valves are needed to enable the transfer of drainage water around the site for recycling.

3) Example Designs

Several subsurface drainage system designs will be done using parameters typical of the geologic conditions on the west side of the San Joaquin Valley. The soil is a silty clay loam with a water table that is within four feet of the soil surface. The winter rainfall is minimal and generally is not a factor in deep percolation losses. The principal irrigation system is surface irrigation. The examples will demonstrate the effect on lateral spacings for a combination of deep percolation losses that result from a single irrigation system or combination of systems. The actual system employed is irrelevant to the design. The important fact is the depth of deep percolation resulting from the design.

In this example, the crop is cotton and a fully developed root zone of approximately four feet is assumed. Depending on the year, there are typically three-to-five irrigations a year on cotton, each one applying about five inches of water. The first simulation assumes a uniform deep percolation loss based on surface irrigation with an irrigation efficiency typical of surface irrigation (75%). This means approximately 1.25 inches is deep percolation losses from each event. The second simulation uses sprinklers for the pre-plant and first irrigation to reduce total deep percolation losses. The next simulation uses sprinkler irrigation for the entire season. The last simulation demonstrates the effect of drip irrigation on the system design. Sprinkler irrigation is used for pre-plant irrigation for salinity control. Each of the simulations includes a pre-plant irrigation occurring in January. The pre-plant is done either by surface irrigation or sprinkler. The purpose of the simulations is to emphasize the impact of good water management on the drainage system design. The input data are summarized in Table 1, along with the resulting drain spacing.

The saturated hydraulic conductivity was set equal to three feet/day. The specific yield is 0.13. The drainage laterals were installed at a depth of seven feet. The barrier was assumed to be at 10 feet, and the aerated zone was 4 feet.

Table 3-1. Drain design simulation summary.

Date	Deep percolation (in)			
	Base (surface)	Sprinkler then surface	Sprinkler only	Sprinkler then drip
Jan. 1	1.5	.9	.9	.9
May 15	1.25	.75	.75	.4
May 29	1.25	1.25	.75	.4
July 26	1.25	1.25	.75	.4
August 17	1.25	1.25	.75	.4
Drain Spacing (ft)	313	339	431	536

The lateral spacing for drains installed on the west side of the Valley typically have spacing similar to the base value given in Table 3-1. When the early irrigations were improved, there was a modest increase in drain spacing for the sprinkler followed by surface irrigation. This value may be further increased if a detailed analysis is done to determine the actual deep percolation losses in the last two irrigations of the season. Research in the Valley has shown that deep percolation nearly ceases by the end of the growing season.

Simply changing from surface irrigation to sprinkler irrigation resulted in an increase in drain spacing by over 100 feet. There may be improved yields that result from improved aeration with the use of sprinklers. Likewise, there should be additional benefits from managing surface runoff from sprinklers.

The most dramatic improvement results from switching to drip irrigation while using sprinkler irrigation for salinity control in the pre-plant irrigation. In the example design, the lateral spacing increased by over 200 ft. This would result in a considerable savings in the construction of a new system. There has been a major shift to drip irrigation on the west side of the Valley because of the lack of drainage service and the ability of a well managed drip system to limit deep percolation losses.

These above simulations were done only based on the volume of applied irrigation water and not with a consideration of water quality. However, the water quality aspects of an IFDM system are related to the leaching fraction in an individual production area. In the production area with salt-sensitive crops, the above designs would be typical of the lateral spacing for the given irrigation system when using good quality water. The question is what happens when poor quality water is used. In those cases, the leaching requirement is determined as demonstrated in the irrigation design section and compared to the actual leaching fraction that is estimated to occur as a result of the irrigation inefficiency. If the LR < LF, no additional water is required beyond what is needed to meet the crop requirement using the given water quality. It was demonstrated in the irrigation design section in Appendix pages A-10 to A-21 that with the groundwater quality found on the Valley's west side, surface irrigation inefficiency will result in adequate deep percolation. This would be comparable to the base condition given in Table 3-1. This suggests that many of the existing drainage systems will be adequate to meet the drainage water requirements in the salt-tolerant crop production area.

To summarize, the existing procedures used in the design of subsurface drainage systems in the Valley will be adequate for the design of the lateral spacings of the drainage systems to be used in an IFDM system. Careful irrigation management will be essential to limiting the cost of new drainage systems.

4) Drain system layout for water table control

This is one area that is a major departure from existing practice in the design and installation of subsurface drainage systems. Past practice has been to design systems for continuous operation, which means drains that discharge to surface ditches were allowed to flow without interruption. When a drainage system discharged to a sump, the pump was operated continuously and was controlled by a set of limit switches that controlled the water level in the sump. There was never any intention of controlling the water table position in the field because of the concern for salination of the root zone. In these situations, the field laterals were installed parallel to the surface grade of the field and a sub-main collected the flow from each drain and carried it to the sump. The lateral depth and grade and sub-main depth and grade were adjusted to ensure that the drainage flow went to the sump.

The above configuration of laterals and sub-mains limits the ability to control the water table in the field without installing control structures in multiple locations in the field. If the water table position is controlled only at the tail end of the field, that portion of the field will be water-logged while the head end has no control. To correct this, the drainage laterals must be installed perpendicular to the surface grade and the sub-main collector will be parallel to the surface grade. In this case, the grade needed for flow will have to be created during the installation process by having the lateral depth increase across the field. This means that the drains may be 5.5 feet deep on one side and seven feet deep on the downstream end. Control structures can be added to each lateral or intermittently along the sub-main to control the water table. These structures can be placed off the edge of the field out of the way of cultural operations. Research by Ayars (1999) has demonstrated the operation of control structures on properly configured laterals. The results from the study demonstrated that the irrigation requirement was reduced when the water table was managed.

If the designer opts for deep drains with control structures there will be an opportunity to store water in the soil profile during periods of low potential ET. Deep, wide drain lateral spacing will not result in deep flow lines if the water table is controlled.

As the manager becomes familiar with the system, he or she will recognize that late in the season the crop may be using water from shallow groundwater and the irrigation schedule will have to be modified to account for this contribution. The general effect will be to lengthen the time between irrigations. Research by Kite and Hanson (1984) and Ayars and Schoneman (1986) has demonstrated that crops will use significant quantities of water from the water table. The research by Kite and Hanson (1984) demonstrated one less irrigation on cotton as did the research of Ayars and Schoneman (1986). The management problem will be to develop irrigation scheduling methodologies that account for the in-situ contribution. Kite and Hanson (1984) used leaf water potential to schedule the irrigation of cotton and Ayars and Hutmacher (1994) developed crop coefficients that accounted for the in-situ use.

However, there is much work that still must be done to develop data for a wide range of crops and groundwater conditions. In the interim, the manager should be aware of the potential and observe the system to see if there are any opportunities to induce in-situ crop water use. The best potential use area will probably be in the salt-tolerant production area. In this case, the crop salt-tolerance and the groundwater quality will be a closer match than in the salt-sensitive cropping area. Ayars and Hutmacher (1994) demonstrated that a crop will use significant quantities of water from saline water with an EC twice the value of the threshold that yield reductions occur.

5) Drainage system design for salt management

This will be a new approach for the designer and farmer to consider. For the most part, the drainage design criteria are developed to provide an aerated zone and by default to protect the soil from salinization by controlling the water table depth to minimize the upward flow of saline water from the water table. These are still valid criteria. However, with an IFDM system, some consideration needs to be given to modifying the criteria to reduce salt loading, Ayars et al. (1997). In general, the deeper and wider drainage laterals are installed, the greater will be the flow lines into the profile. This will result in large salt loading if there are large salt stores in the profile, which is the situation in the Valley and many other places in the world.

One alternative is to use a shallower drain placement that will have shallower flow lines compared to a deep installation with the same spacing. Shallower placement also will result in reduced drainage flow in uncontrolled drainage systems, which is often called over-drainage. Shallower drain lateral placement also will result in the mid-point water table depth being closer to the surface. This may require additional management for salinity control. Providing outlet control on a deep installation also will limit the depth of the flow lines. Deeper placement will provide other options concerning water management and storage.

When shallow placement is considered, switching to irrigation systems with high efficiencies will maintain good lateral spacing. A lateral spacing of 549 feet was calculated using a lateral depth of five feet and a mid-point water table depth of three feet. The deep percolation schedule used was the sprinkler - drip combination given in Table 3-1. In situations where there is some leakage through the impermeable barrier or lateral flow from the area, a shallow drainage system might be suitable. These shallower systems will require careful management, but many farmers in the drainage-impacted areas already have experience with managing salt in undrained land that would contribute to the management of these systems.

6) Drainage flow calculations

The Agricultural Drainage Planning Program can be used to estimate drainage flow. The ADPP program is first used to calculate the drainage spacing using the transient analysis. One of the outputs from this program is the calculated daily height of the water table above the drains for a design. This number can be used along with the flow equation for drain discharge from spaced laterals found in the USBR drainage manual to estimate daily flow. The resulting daily discharge can be calculated and summed with the flows from the other drainage systems in the IFDM system to calculate the discharge from the system. The calculation described above assumes that there is always drainage flow but this is often not the case in the field. This procedure will provide a conservative estimate of the flow from the individual drainage systems, which can be summed.

Using the above-described procedure and the data from the base design case described in Table 3-1, it was estimated that the flow from 160 ac. was 74 ac-ft. from an applied water of approximately 440 ac-ft. Drainage flow also was estimated for the case using sprinkler for irrigation and drip for the in-season irrigation. The total estimated flow was 36 ac-ft from 160 acres.

7) Summary

Designing a subsurface drainage system to be used in the drainage water recycling component of an IFDM system requires minor modifications from the existing drainage design procedures that have been developed by the USBR and the NRCS. The biggest change will be in adopting an active management program for the drainage system that integrates the operation of the irrigation system. The general layout of the drainage system will have to be changed to accommodate controlling the water table, and control structures will have included in the design. These control structures will include a weir structure that can be raised and lowered as needed.

The drainage system will have to be managed differently throughout the year. Early in the year, the goal may be to store water because there is no demand for irrigation or the evaporative demand is low, while later in the season water is stored to meet crop water requirements. There may be a time that the water table is dropped to allow some leaching. The opportunities are endless and the drainage system should be included as an active part of the overall water management scheme in an IFDM system.

J. Solar Evaporator Design

When setting out to design a solar evaporator, the designer must first understand that each situation (farm) is different, and there is no one way to design and specify a universally acceptable solar evaporator. The following are suggestions and guidelines for the process of designing a solar evaporator.

1. Start by reviewing the state Solar Evaporator Regulations. The regulations specify the design, construction, operation, and closure requirements.

(See Appendix pages A-79 to A-88 for the regulations.)

2. Gather information from the Landowner/Operator

The following categories of information will be required by the designer during the solar evaporator design. Much of the information will have been gathered during the initial studies of the IFMD location. These data are needed to site the evaporator out of a flood zone and to quantify the flood risk on the property. As noted in the regulations the distance between the bottom of the evaporator and the position of the water table is critical in the design to ensure that percolation from the evaporator will not impact groundwater quality. The rainfall data are needed to quantify the potential storage requirements in the system.

- Drainage problems affecting the farm area
- Surface flow from adjacent properties during heavy rainfall
- Rainfall
- Flooding from streams
- High water table areas
- Barriers affecting surface flow

3. Gather data required for the Technical Report; which is a part of the Notice of Intent that must be submitted to the RWQCB along with the solar evaporator design.

The following is a sample Table of Contents for a technical report and operational plan for the design of a solar evaporator (developed by the Department of Water Resources in February 2005 with minor revisions by CIT in August 2005). The table lists the types of information that an engineer may need to consider in the technical report and operational plan as part of the Notice of Intent application permit process.

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Design of Solar Evaporator . . . .

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- Section, Township, Range
- APN, County

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- 25-Year, 24-Hour Maximum Precipitation Event
- Floods with a 100-Year Return Period
- Catchment Basin Design Specifications

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- Soil Gradation Results
- Well Logs
- 2000 Shallow Groundwater Map
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Prevent Migration of Constituents from Solar Evaporator into Vadose Zone

Weather Data and Water Balance Analyses

Wind Drift

Groundwater Monitoring Data

Adequate Protection of Avian Wildlife

Groundwater Monitoring and Recordkeeping

Flow Meters

Storage of Salt Isolated in the Solar Evaporator

4. Review designs of solar evaporators on other farms. (Eg. AndrewsAg and Red Rock Ranch)

Chapter 2 describes the general design of the solar evaporator at AndrewsAg. The 20-acre solar evaporator at AndrewsAg was established in two of the cells of the former 100 acres of evaporation ponds.

The Department of Water Resources has recently completed a new design for the solar evaporator at Red Rock Ranch. (See Appendix pages A-22 to A-25 for project abstract and CD for design information).

One of the major differences between the solar evaporators at the two farms is that one stores the salt evaporite (AndrewsAg), and the other processes the salt for harvest and utilization (Red Rock Ranch).

Each solar evaporator design will be tailored to the farming operation and site characteristics. The ultimate design will be the responsibility of the designer.

See Appendix (pages A-79 to A-88) for solar evaporator regulations.